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Original Article

Sedentary behavior and anxiety-induced sleep disturbance among 181,093 adolescents from 67 countries: a global perspective

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ABSTRACT

Objectives: Sleep problems are burdensome in adolescents. Understanding modifiable environmental risk factors is essential. There is evidence that physical activity is protective against sleep problems in adolescents. However, the association between sedentary behavior (SB) and anxiety-induced sleep disturbance has not been investigated.

Methods: Using cross-sectional data from the Global school-based Student Health Survey, we explored the association between SB and anxiety-induced sleep disturbance in 181,093 adolescents [mean (standard deviation, SD) age 13.7 (1.0) years; 48.4% girls] from 67 countries, controlling for confounders (including physical activity). Adolescents reported anxiety-induced sleep disturbance during the past 12 months, and SB, which was a composite variable assessing time spent sitting and watching television, playing computer games, talking with friends during a typical day excluding the hours spent sitting at school and doing homework. Multivariable logistic regression analysis was conducted and a countrywide meta-analysis undertaken.

Results: Overall, 7.8% of adolescents had anxiety-induced sleep disturbance. The prevalence of SB was: <1 h/day 39.9%; 1–2 h/day 33.8%; 3–4 h/day 15.4%; 5–8 h/day 7.4%; and >8 h/day 3.6%. Compared to <1 h/day of SB, >8 h/day was associated with a 2.27 [95% confidence interval (CI) = 1.98–2.62] times higher odds for anxiety-induced sleep disturbance. The association was similar among both sexes. The pooled odds ratio for anxiety-induced sleep disturbance when being sedentary ≥3 h/day was 1.42 (95% CI = 1.36–1.48) with only a small degree of between-country heterogeneity (I^2 = 41.4%).

Conclusions: Future longitudinal data are required to confirm/refute the findings to inform public interventions which aim to reduce anxiety and sleep disturbance in adolescents.

1. Introduction

Anxiety is a major cause of sleep disturbance in adolescents [1], while vice versa, sleep disturbance is associated with higher risk for developing symptoms of anxiety [1,2]. Sleep problems and anxiety

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are both commonly associated with other psychiatric disorders and are independent risk factors for suicidality, substance use and cardiovascular diseases in adolescence, indicating that treating both in early adolescence may reduce risk for adverse outcomes [3–6].

While cognitive behavioral treatments have proven efficacy for adolescent anxiety and sleep disturbance, and online methods seem to offer promising options [3,7], some adolescents may be unreceptive, reluctant, and ambivalent towards psychotherapy [8]. Moreover, these treatment modalities are not always available in low-resourced settings [9]. Specific services for early detection and cost-effective, easily accessible, and widely appealing interventions for mental health problems are therefore highly needed [10]. From a public health perspective, it is essential to understand the risk factors that are associated with anxiety-induced sleep disturbance in adolescents such that targeted low-threshold interventions can be developed to assist in prevention and treatment.

Two related lifestyle behaviors that have been associated with anxiety and sleep disturbance are physical activity participation and sedentary behavior. Physical activity can be defined as any bodily movement produced by skeletal muscles that requires energy expenditure [11]. Previous research [12] demonstrated that chronic vigorous exercise (ie, structured physical activity) is positively related to adolescents' sleep and psychological functioning. As such, adolescents who frequently exercise vigorously report better sleep patterns including higher sleep quality, shortened sleep onset latency, and fewer awakenings after sleep onset, as well as less tiredness, increased concentration, and lower anxiety and fewer depressive symptoms during the day [12]. Sedentary behavior refers to any waking behavior characterized by an energy expenditure $\leq$1.5 metabolic equivalents (METs), while in a sitting, reclining or lying posture [13]. Sedentary behavior is highly prevalent among adolescents. In a study in 34 different countries involving 72,845 school-going adolescents, more than one-third spent 3 or more hours per day in sedentary activities, excluding the hours spent sitting at school and doing homework [14]. Though the mechanisms linking anxiety-induced sleep disturbance and sedentary behavior are not explored yet, there is some evidence from studies in adults that sedentary behavior may induce anxiety [15–18] while it is associated with an increased risk for sleep disturbances [19].

Because there are no data on the association between anxiety-induced sleep disturbance and sedentary behavior in adolescents, the aim of the current study was to fill this gap. To do so, we examined data from the Global School-based Student Health Survey (GSHS), which included data from 67 countries from six World Health Organization (WHO) regions that predominantly consist of low- and middle-income countries (LMICs) [African Region (AFR), Region of the Americas (AMR), Eastern Mediterranean Region (EMR), European Region (EUR), South-East Asia Region (SEAR), Western Pacific Region (WPR)]. We hypothesized that more time spent sedentary is, independent from age, sex, socioeconomic status and physical activity participation, associated with a higher odds for anxiety-induced sleep disturbance.

2. Methods

2.1. The survey

Publicly available data from the GSHS were analyzed. Details on this survey can be found at http://www.who.int/chp/gshs and http://www.cdc.gov/gshs. Briefly, the GSHS was jointly developed by the WHO and the US Centers for Disease Control and Prevention (CDC), and other UN allies. The core aim of this survey was to assess and quantify risk and protective factors of major non-communicable diseases. The survey draws content from the CDC Youth Risk Behavior Survey (YRBS) for which test–retest reliability has been established [20]. The survey used a standardized two-stage probability sampling design for the selection process within each participating country. For the first stage, schools were selected with probability proportional to size sampling. The second stage involved the random selection of classrooms which included students aged 13–15 years within each selected school. All students in the selected classrooms were eligible to participate in the survey regardless of age. Data collection was performed during one regular class period. The questionnaire was translated into the local language in each country and consisted of multiple-choice response options; students recorded their response on computer-scannable sheets. All GSHS surveys were approved, in each country, by both a national government administration (most often the Ministry of Health or Education) and an institutional review board or ethics committee. Student privacy was protected through anonymous and voluntary participation, and informed consent was obtained as appropriate from the students, parents, and/or school officials. Data were weighted for non-response and probability selection.

From all publicly available data, we selected all nationally representative datasets that included the variables pertaining to this analysis. If there were more than two datasets from the same country, we chose the most recent dataset. A total of 67 countries were included in the current study. The characteristics of each country or survey are provided in Table 1. For the included countries, the survey was conducted between 2003 and 2015, and consisted of 12 high-income, 46 middle-income, and nine low-income countries (11 AFR countries; 21 AMR countries; 13 EMR countries; one EUR country; eight SEAR countries; and 13 WPR countries).

2.2. Anxiety-induced sleep disturbance (dependent variable)

Anxiety-induced sleep disturbance was assessed with the question 'During the past 12 months, how often have you been so worried about something that you could not sleep at night?' with answer options: 'never,' 'rarely,' 'sometimes,' 'most of the time,' and 'always'. As in a previous GSHS study, those who answered 'most of the time' or 'always' were considered to have anxiety-induced sleep disturbance [21].

2.3. Sedentary behavior (independent variable)

Sedentary behavior was assessed with the question 'How much time do you spend during a typical or usual day sitting and watching television, playing computer games, talking with friends, or doing other sitting activities?' with six answer options: <1, 1–2, 3–4, 5–6, 7–8, and >8 h/day. This excluded time spent sitting while at school and when doing homework. This variable was used as a five-category variable (5–6 and 7–8 h/day were merged as the proportion of those who replied 7–8 h/day was small) or a dichotomized variable ($\geq$3 h/day or not) [14]. This question was based on the National Health And Nutrition Examination Survey (NHANES) questionnaire from 1999–2000, and modified for use in children and has been used in recent research.

2.4. Confounding variables

These included age, sex, food insecurity, and physical activity. As in a previous GSHS study, food insecurity was used as a proxy for socioeconomic status as there were no variables on socioeconomic status in the GSHS [22]. Specifically, this was assessed by the question 'During the past 30 days, how often did you go hungry because there was not enough food in your home?' Response

Table 1
Survey characteristics and prevalence of sedentary behavior and anxiety-induced sleep disturbance.

Country income[a]	Country	Year	Response rate (%)[b]	*N*	Sedentary behavior (%)[c,d]	Anxiety-induced sleep disturbance (%)[c,e]
Low	Afghanistan	2014	79	1493	22.8 (17.2–29.7)	21.7 (18.6–25.1)
	Benin	2009	90	1170	18.4 (15.3–22.0)	14.6 (12.4–17.0)
	Cambodia	2013	85	1812	9.9 (7.7–12.7)	3.8 (2.9–4.8)
	Kenya	2003	84	2971	37.6 (34.2–41.1)	15.7 (13.0–18.8)
	Mozambique	2015	80	668	40.6 (33.6–48.1)	8.7 (5.4–13.9)
	Myanmar	2007	95	2227	10.0 (8.1–12.3)	1.8 (1.2–2.7)
	Tanzania	2014	87	2615	20.4 (17.3–23.8)	6.2 (5.0–7.7)
	Uganda	2003	69	1904	27.1 (23.5–31.1)	9.9 (7.4–13.1)
	Zambia	2004	70	1365	32.6 (28.9–36.6)	25.8 (23.1–28.7)
Lower middle	Bangladesh	2014	91	2753	14.1 (10.8–18.4)	4.5 (3.6–5.7)
	Belize	2011	88	1600	36.1 (31.8–40.6)	11.7 (10.1–13.6)
	Bolivia	2012	88	2804	24.2 (21.0–27.8)	7.1 (6.1–8.3)
	Djibouti	2007	83	962	31.4 (27.0–36.1)	13.0 (9.9–16.9)
	East Timor	2015	79	1631	15.2 (12.6–18.3)	7.7 (5.4–10.9)
	Egypt	2006	87	4981	25.5 (20.6–31.2)	10.3 (8.8–12.1)
	El Salvador	2013	88	1615	33.6 (29.1–38.5)	6.1 (5.0–7.5)
	Fiji	2010	90	1495	28.4 (23.2–34.4)	16.8 (11.1–24.5)
	Ghana	2012	82	1110	18.3 (14.9–22.4)	11.9 (9.5–14.9)
	Guatemala	2015	82	3611	22.5 (17.4–28.5)	6.5 (4.9–8.6)
	Guyana	2010	76	1973	35.9 (29.9–42.3)	14.6 (12.9–16.4)
	Honduras	2012	79	1486	30.4 (27.8–33.2)	5.9 (4.6–7.5)
	India	2007	83	7330	22.3 (20.2–24.6)	7.5 (6.8–8.2)
	Indonesia	2015	94	8806	25.7 (23.8–27.7)	4.4 (3.8–5.2)
	Jordan	2007	100	1648	38.1 (34.9–41.4)	19.7 (14.7–25.9)
	Kiribati	2011	85	1340	14.9 (13.0–17.1)	8.2 (6.6–10.2)
	Laos	2015	70	1644	17.4 (14.9–20.3)	2.2 (1.5–3.3)
	Macedonia	2007	93	1550	50.3 (45.0–55.6)	5.8 (4.7–7.0)
	Maldives	2009	80	1981	44.4 (39.8–49.1)	13.3 (9.8–17.8)
	Mauritania	2010	70	1285	39.2 (33.8–44.8)	10.9 (7.5–15.4)
	Mongolia	2013	88	3707	39.8 (36.0–43.7)	5.1 (4.2–6.1)
	Morocco	2010	92	2405	25.9 (23.0–29.0)	14.6 (12.3–17.3)
	Pakistan	2009	76	4998	7.6 (6.0–9.5)	7.8 (6.2–9.7)
	Philippines	2015	79	6162	30.5 (26.8–34.5)	10.2 (9.2–11.2)
	Samoa	2011	79	2200	37.5 (34.3–40.8)	26.8 (23.3–30.5)
	Solomon Islands	2011	85	925	27.8 (22.0–34.4)	13.4 (9.9–17.9)
	Sri Lanka	2008	89	2504	33.4 (30.9–36.1)	4.4 (3.7–5.3)
	Syria	2010	97	2929	25.6 (20.6–31.4)	15.2 (12.9–17.8)
	Tonga	2010	80	1946	28.3 (25.5–31.3)	14.6 (13.0–16.3)
	Tunisia	2008	83	2549	24.1 (20.4–28.2)	18.7 (16.5–21.2)
	Vanuatu	2011	72	852	20.0 (15.4–25.5)	4.2 (2.6–6.8)
Upper middle	Antigua & Barbuda	2009	67	1235	53.7 (49.8–57.6)	13.9 (11.3–17.0)
	Argentina	2012	71	21,528	49.1 (47.3–50.9)	7.8 (6.9–8.7)
	Botswana	2005	95	1397	35.7 (31.2–40.4)	17.8 (13.6–22.8)
	Costa Rica	2009	72	2265	43.1 (39.7–46.6)	4.0 (3.2–5.1)
	Grenada	2008	78	1299	41.4 (37.6–45.2)	9.7 (7.8–12.0)
	Iraq	2012	88	1533	25.6 (21.7–30.0)	11.2 (9.6–13.0)
	Lebanon	2011	87	1982	47.0 (42.6–51.5)	10.3 (8.5–12.4)
	Malaysia	2012	89	16,273	42.6 (40.4–44.8)	4.4 (4.0–4.9)
	Namibia	2013	89	1936	36.9 (33.5–40.5)	12.3 (10.3–14.6)
	Peru	2010	85	2359	27.4 (24.0–31.1)	9.1 (7.5–11.0)
	St. Vincent & the Grenadines	2007	84	1188	39.7 (36.5–43.1)	13.5 (11.4–16.1)
	St. Lucia	2007	82	1072	53.5 (50.2–56.7)	10.9 (9.3–12.7)
	Suriname	2009	89	1046	39.1 (34.7–43.6)	8.3 (6.7–10.2)
	Thailand	2015	89	4132	51.0 (48.0–53.9)	8.3 (6.5–10.5)
	Tuvalu	2013	90	679	15.4 (12.6–18.7)	7.0 (5.1–9.5)
High	Bahamas	2013	78	1308	56.0 (52.3–59.6)	14.5 (12.0–17.5)
	Barbados	2011	73	1504	63.0 (59.5–66.2)	9.1 (7.7–10.7)
	Brunei Darussalam	2014	65	1824	52.8 (50.1–55.4)	8.5 (7.1–10.1)
	Cayman Islands	2007	79	1147	57.0 (53.9–60.1)	11.0 (9.3–13.0)
	Curaçao	2015	83	1498	57.1 (54.0–60.2)	9.1 (8.0–10.4)
	Kuwait	2015	78	2034	62.2 (56.0–68.0)	18.9 (16.2–21.9)
	Qatar	2011	87	1781	47.7 (44.0–51.5)	17.9 (15.3–20.8)
	Seychelles	2015	82	2061	50.1 (47.4–52.9)	10.9 (9.4–12.5)
	St. Kitts & Nevis	2011	70	1471	57.2 (53.1–61.3)	8.7 (6.8–11.0)
	Trinidad & Tobago	2011	90	2363	45.0 (40.8–49.4)	7.1 (5.6–9.1)
	United Arab Emirates	2010	91	2302	49.0 (45.4–52.6)	14.4 (12.9–16.1)
	Uruguay	2012	77	2869	59.7 (56.0–63.3)	5.0 (3.9–6.3)

[a] Country income level was based on the World Bank classification at the year of the survey in the respective countries.
[b] Response rate was calculated as school response rate multiplied by student response rate.
[c] Estimates are sex- and age-adjusted.
[d] ≥3 h of sedentary behavior per day.
[e] Anxiety-induced sleep disturbance was defined as answering 'most of the time' or 'always' to the question 'During the past 12 months, how often have you been so worried about something that you could not sleep at night?'

alternatives were categorized as 'never,' 'rarely/sometimes,' and 'most of the time/always' [23]. To assess levels of physical activity, questions that represented the PACE + Adolescent Physical Activity Measure [24] were asked. This measure has been shown to be valid and reliable [24]. The questions asked about the number of days with physical activity of at least 60 min during the past seven days. Those who engaged in ≥5 days of at least 60 min of physical activity in the past week were considered to have a sufficient amount of physical activity [14].

2.5. Statistical analysis

Statistical analyses were performed with Stata 14.1 (Stata Corp LP, College station, Texas). The analysis was restricted to those aged 12–15 years. Age- and sex-adjusted prevalence of sedentary behavior of ≥3 h/day and anxiety-induced sleep disturbance were calculated using the proportions derived from the overall sample as the standard population. We used multivariable logistic regression analysis to estimate the association between sedentary behavior (independent variable) and anxiety-induced sleep disturbance (dependent variable) using the overall, sex-wise, and country-wise samples. The exposure variable was the five-category sedentary behavior variable when the overall or sex-wise samples were used. However, for country-wise analyses, we used the dichotomized sedentary behavior variable to obtain stable estimates, as the sample size in each country was small. In order to assess between-country heterogeneity in the association between sedentary behavior and anxiety-induced sleep disturbance, we calculated the Higgin's I^2 which represents the degree of heterogeneity that is not explained by sampling error with a value of <40% often considered as negligible and 40–60% as moderate heterogeneity [25]. A pooled estimate was obtained by combining the estimates for each country into a fixed-effect meta-analysis (overall and by country-income level).

All regression analyses were adjusted for age, sex, food insecurity, and physical activity with the exception of the sex-wise and country-wise analyses which were not adjusted for sex and country, respectively. Adjustment for country was performed using fixed-effects models as in a previous GSHS study [23]. All variables were included in the regression analysis as categorical variables with the exception of age (continuous variable). Sampling weights and the clustered sampling design of the surveys were taken into account to obtain nationally representative estimates. Results from the logistic regression analyses are presented as odds ratios (ORs) with 95% confidence intervals (CIs). The level of statistical significance was set at $p < 0.05$.

3. Results

The final sample comprised 181,093 adolescents aged 12–15 years [mean (SD) age 13.7 (1.0) years; 48.4% females]. The prevalence of sedentary behavior was: <1 h/day 39.9%; 1–2 h/day 33.8%; 3–4 h/day 15.4%; 5–8 h/day 7.4%; and >8 h/day 3.6%. Overall, 7.8% of the students had anxiety-induced sleep disturbance. The age- and sex-adjusted prevalence of ≥3 h/day of sedentary behavior ranged from 7.6% (Pakistan) to 63.0% (Barbados) while the corresponding figures for anxiety-induced sleep disturbance were 1.8% (Myanmar) to 26.8% (Samoa) (Table 1, Fig. 1). The prevalence of anxiety-induced sleep disturbance increased linearly beyond sedentary behavior of 1–2 h/day but a slight drop in the prevalence was observed at 1–2 h/day compared to <1 h/day in the overall and sex-wise samples (Fig. 2). This was also seen in the multivariable analysis where there was a significant 10% decrease in the odds for anxiety-induced sleep disturbance for sedentary behavior of 1–2 h/day compared to <1 h/day, although beyond 1–2 h/day, the odds for anxiety-induced sleep disturbance increased in a dose-dependent fashion in the overall sample (Table 2). Overall, compared to <1 h/day of sedentary behavior, >8 h/day was associated with a 2.27 (95% CI = 1.98–2.62) times higher odds for anxiety-induced sleep disturbance. The association was similar among both sexes. The country-wise estimates of the association between ≥3 h/day of sedentary behavior and anxiety-induced sleep disturbance are shown in Fig. 3. Sedentary behavior was significantly associated with higher odds of anxiety-induced sleep disturbance in 64 of the 67 countries. Particularly high ORs were observed in Vanuatu (OR = 4.53), El Salvador (OR = 2.50), and Tanzania (OR = 2.42). The overall estimate based on a meta-analysis was OR = 1.42 (95% CI = 1.36–1.48) with only a small degree of between-country heterogeneity ($I^2 = 41.4\%$). Estimates by country-income level were similar.

4. Discussion

4.1. General findings

To the authors' knowledge, this is the first multinational study examining the link between sedentary behavior and the presence of anxiety-induced sleep disturbance in general. After adjustment

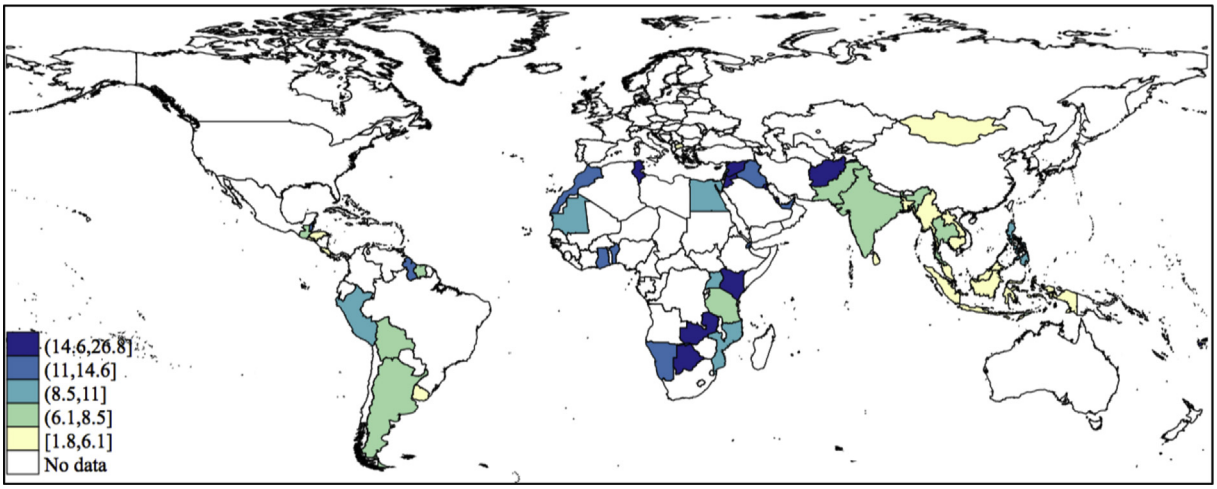

Fig. 1. Age- and sex-adjusted prevalence of anxiety-induced sleep disturbance. Anxiety-induced sleep disturbance was defined as answering 'most of the time' or 'always' to the question "During the past 12 months, how often have you been so worried about something that you could not sleep at night?"

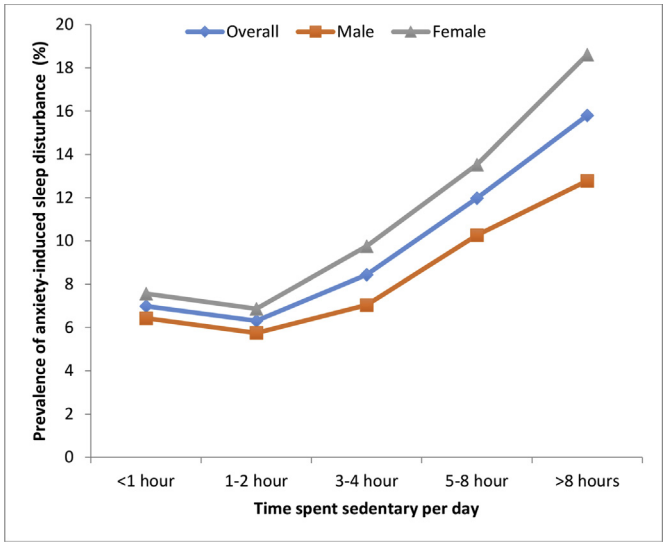

Fig. 2. Prevalence of anxiety-induced sleep disturbance by time spent sedentary. Anxiety-induced sleep disturbance was defined as answering 'most of the time' or 'always' to the question "During the past 12 months, how often have you been so worried about something that you could not sleep at night?".

for age, sex, food insecurity as a proxy-measure for socioeconomic status and physical activity, adolescents who were sedentary for >8 h/day had a 2.27 (95% CI = 1.98–2.62) times higher odds for anxiety-induced sleep disturbance than adolescents being sedentary <1 h/day. The association was similar among both sexes. The pooled odds for anxiety-induced sleep disturbance when being sedentary for ≥3 h/day was 1.42 (95% CI = 1.36–1.48) with an almost negligible level of between-country heterogeneity. Of interest is the slight drop in the prevalence of anxiety-induced sleep disturbance in those adolescents engaging in 1–2 h of sedentary behavior per day compared to <1 h/day. One hypothesis is that more than 1 h spent sedentary, for example viewing TV, might be a measure-of-proxy for a higher socioeconomic status (having a TV at home) in particular in low-income countries. Those without access to a TV might be less sedentary, but might also have a lower socioeconomic status, which is a known risk factor for sleep disturbance in adolescents [26]. Alternatively, <1 h/day of sedentary behavior may itself be an indicator of an individual's hyperactivity and inability to rest easily, which in turn itself could be a predisposal towards anxiety and sleep disturbance.

Though the mechanisms linking anxiety-induced sleep disturbance and sedentary behavior beyond 2 h are not yet explored in adolescents, there is some evidence from adult studies that sedentary behavior may induce anxiety [15,17] while it is associated with an increased risk of sleep problems [19]. For example, a recent randomized controlled trial (RCT) reported that, when time spent sedentary was experimentally increased for 1 week by eliminating exercise and reducing steps to ≤5000 steps/day in an active young adult population, anxiety symptoms were significantly increased [16]. In young adults, being more sedentary over two weeks increased inflammatory markers such as IL-6, which is also implicated in anxiety and in sleep problems. Therefore, a systemic inflammatory process may underlie the association of sedentary time with anxiety-induced sleep disturbance, in particular since provisional evidence suggests that standing and breaking up prolonged periods of sedentary time can improve inflammatory biomarker profiles [27–29]. Besides this, there might also be other pathophysiological mechanisms. For example, it is known that being physically active instead of being sedentary is implicated in a range of physiological changes, including potential alterations of circadian rhythms [30]. Being active may acutely (ie, within minutes) alter melatonin levels and result in a shift of the onset of nocturnal melatonin [30]. However, in our study, sedentary behavior was significantly associated with anxiety-induced sleep disturbance regardless of physical activity. Finally, and vice versa, it might be hypothesized that adolescents with anxiety-induced sleep disturbance are watching more TV and are participating more in sitting activities when they cannot sleep.

The most plausible hypothesis is however that more time being sedentary may induce anxiety-induced sleep disturbance via inflammatory mechanisms, in particular since a meta-analysis in adults demonstrated that the opposite is less likely; ie, although sleep problems may lead to daytime sleepiness, no association with a sedentary lifestyle was found [19].

4.2. Limitations and future research

Our findings should be interpreted in light of several potential limitations. First, the study is cross-sectional, therefore the directionality of the relationships cannot be deduced. Longitudinal studies are required to better disentangle the relationships observed. Second, the study relied on self-reported data, which could have been affected by factors such as recall and social desirability biases [31]. Additionally, self-reported time spent sedentary excluded time at school and when doing homework and therefore is an underestimate of the real time spent sedentary during the entire day. Future research could utilize objective measures of sedentary behavior such as accelerometers-inclinometers. However, the association between sedentary behavior and anxiety-induced sleep disturbance may be dependent on the domain/type of sedentary behavior (cognitively active sedentary behavior, eg, reading and internet use, versus cognitively passive TV viewing), an aspect that is not reliably measured with

Table 2
Association between sedentary time and anxiety-induced sleep disturbance estimated by multivariable logistic regression (overall and by sex).

Time spent sedentary	Overall[a]		Male[b]		Female[b]	
	OR	95% CI	OR	95% CI	OR	95% CI
<1 h/day	1.00		1.00		1.00	
1–2 h/day	0.90*	0.82,0.99	0.91	0.79,1.05	0.90	0.79,1.01
3–4 h/day	1.17**	1.05,1.31	1.11	0.95,1.30	1.22**	1.06,1.41
5–8 h/day	1.71***	1.53,1.92	1.63***	1.34,1.97	1.79***	1.52,2.11
>8 h/day	2.27***	1.98,2.62	1.98***	1.60,2.44	2.51***	2.06,3.05

*$p < 0.05$.
**$p < 0.01$.
***$p < 0.001$.
Anxiety-induced sleep disturbance was defined as answering 'most of the time' or 'always' to the question 'During the past 12 months, how often have you been so worried about something that you could not sleep at night?' CI confidence interval; OR, odds ratio.
[a] Adjusted for age, sex, food insecurity (proxy of socioeconomic status), physical activity, and country.
[b] Adjusted for age, food insecurity (proxy of socioeconomic status), physical activity, and country.

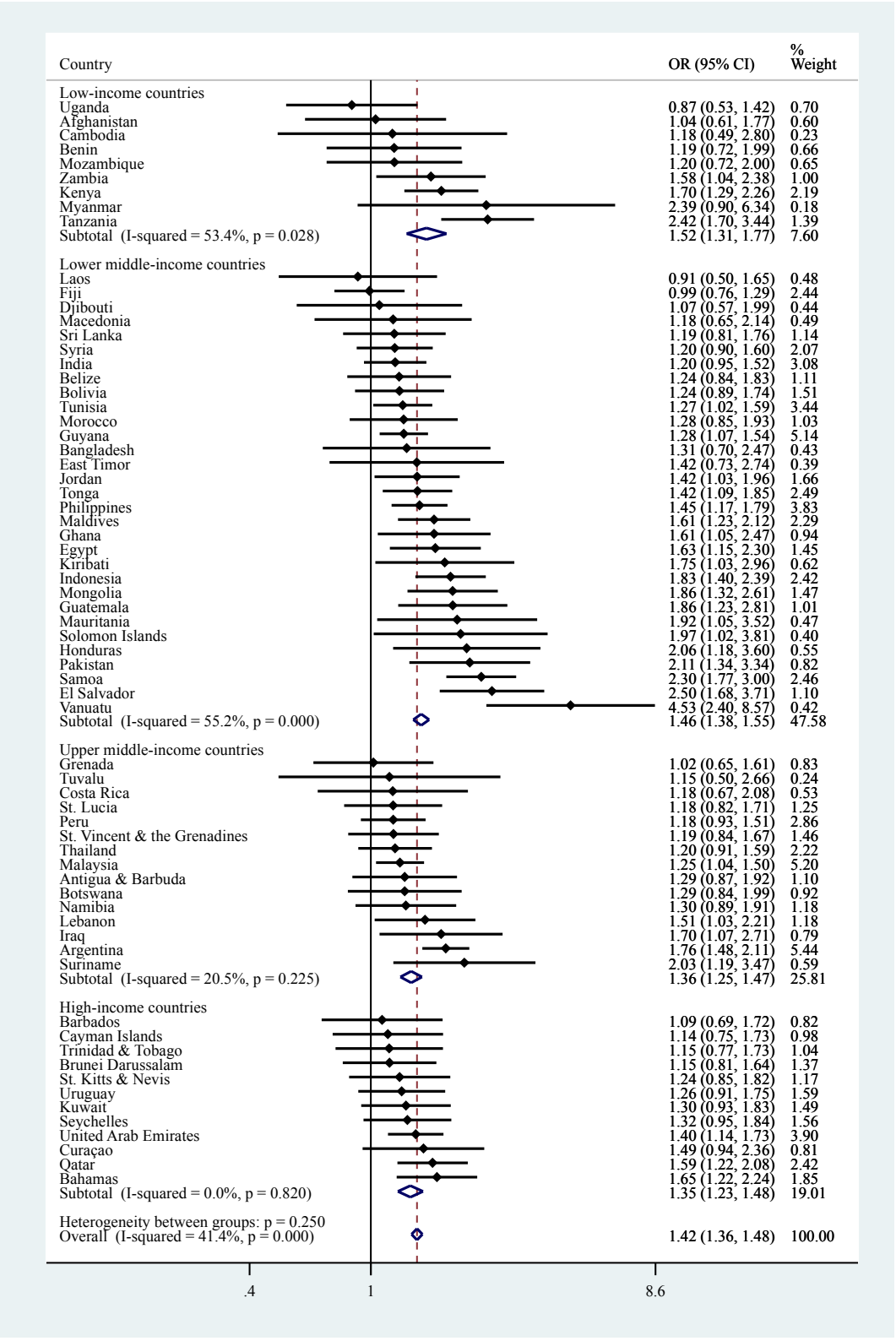

Fig. 3. Country-wise association between ≥3 h/day of sedentary behavior and anxiety-induced sleep disturbance estimated by multivariable logistic regression. Abbreviation: OR Odds ratio; CI confidence interval. Anxiety-induced sleep disturbance was defined as answering 'most of the time' or 'always' to the question "During the past 12 months, how often have you been so worried about something that you could not sleep at night?". Models are adjusted for age, sex, food insecurity (proxy of socioeconomic status), and physical activity. The overall estimate was obtained by meta-analysis with fixed effects.

accelerometers [32]. Moreover, the context in which an adolescent is sedentary should be explored in more detail. For example, on one hand, access to the internet may offer increased access to health information, including mental health support [33], on the other hand, increased use of LED-backlit computer screens might be a risk factor for sleep problems in itself. LED-backlit displays may

cause significant suppression of melatonin, affecting the biological clock and possibly resulting in more sleep problems [34]. Therefore, in order to better understand the relationship between time spent sedentary and anxiety-induced sleep disturbance, a combination of both objective and subjective assessment of sedentary behavior is warranted. Third, varying degrees of bias may have been introduced by interviewing only schoolchildren, especially in countries where schooling attendance rates are low. Nevertheless, the strengths of the study include the largest sample size and the inclusion of nationally representative samples of adolescents attending school. Furthermore, to the best of our knowledge, this is the first study on sedentary behavior and anxiety-induced sleep disturbance in this population.

5. Conclusions

This article provides multinational evidence of a strong relationship between sedentary behavior and anxiety-induced sleep disturbance in adolescents, which was evident even after adjusting for physical activity levels. The consistency of these relationships across numerous countries, and across low-, middle- and high-income settings, adds further weight to the growing evidence for a connection between sedentary behavior and poor mental health in adolescents. Furthermore, given also the wider literature from longitudinal research considering the deleterious impact of sedentary behavior on multiple health outcomes in adolescents [35], it is essential that future research should explore the efficacy and effectiveness of public health interventions that aim to limit the time spent sedentary in this young population. Future longitudinal studies could offer important new targets and strategies for interventions to tackle the sleep-disturbance–sedentary-behavior relationship at its very early stages.

Conflict of interest

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Authors' contributions

Access to Global school-based Student Health Survey data collection was obtained by Dr. Ai Koyanagi. Analyses were performed by Dr. Ai Koyanagi, Dr. Brendon Stubbs and Dr. Davy Vancampfort. Dr. Davy Vancampfort wrote a first draft, which was reviewed and revised in several rounds by the other co-authors. All authors approved the final version and all authors certify that they have participated sufficiently in the work to believe in its overall validity and to take public responsibility for appropriate portions of its content.

Contributors

Dr. Davy Vancampfort- Participated in the conception and design of the study, assisted in the analysis and wrote the manuscript. Dr. Ai Koyanagi - Participated in the design of the study, analyzed the data data and wrote the manuscript. Dr. Tine Van Damme - Participated in the conception and design of the study, and wrote the manuscript. All other co-authors - Revised the different versions of article critically for important intellectual content based on their expert background and approved the final manuscript.

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Conflict of interest

The ICMJE Uniform Disclosure Form for Potential Conflicts of Interest associated with this article can be viewed by clicking on the following link: https://doi.org/10.1016/j.sleep.2019.01.048

References

[1] Mullin BC, Simon SL. Managing insomnia symptoms among adolescents with anxiety disorders. Evid Based Pract Child Adolesc Ment Health 2017;2:123–38.
[2] Armstrong JM, Ruttle PL, Klein MH, et al. Associations of child insomnia, sleep movement, and their persistence with mental health symptoms in childhood and adolescence. Sleep 2014;37:901–9.
[3] de Zambotti M, Goldstone A, Colrain IM, et al. Insomnia disorder in adolescence: diagnosis, impact, and treatment. Sleep Med Rev 2018;39:12–24.
[4] Winsper C, Tang NK. Linkages between insomnia and suicidality: prospective associations, high-risk subgroups and possible psychological mechanisms. Int Rev Psychiatry 2014;26:189–204.
[5] Nadorff MR, Salem T, Winer ES, et al. Explaining alcohol use and suicide risk: a moderated mediation model involving insomnia symptoms and gender. J Clin Sleep Med 2014;10:1317–23.
[6] Matthews KA, Pantesco EJ. Sleep characteristics and cardiovascular risk in children and adolescents: an enumerative review. Sleep Med 2016;18:36–49.
[7] Kendall PC, Peterman JS. CBT for adolescents with anxiety: mature yet still developing. Am J Psychiatry 2015;172:519–30.
[8] Lundkvist-Houndoumadi I, Thastum M. Anxious children and adolescents non-responding to CBT: Clinical predictors and families' experiences of therapy. Clin Psychol Psychother 2017;24:82–93.
[9] Beck A, Nadkarni A, Calam R, et al. Increasing access to cognitive behaviour therapy in low and middle income countries: a strategic framework. Asian J Psychiatr 2016;22:190–5.
[10] Yatham S, Sivathasan S, Yoon R, et al. Depression, anxiety, and post-traumatic stress disorder among youth in low and middle income countries: a review of prevalence and treatment interventions. Asian J Psychiatr 2018;38:78–91.
[11] Caspersen CJ, Powell KE, Christenson GM. Physical activity, exercise, and physical fitness: definitions and distinctions for health-related research. Publ Health Rep 1985;100:126.
[12] Brand S, Gerber M, Beck J, et al. High exercise levels are related to favorable sleep patterns and psychological functioning in adolescents: a comparison of athletes and controls. J Adolesc Health 2010;46:133–41.
[13] Tremblay MS, Aubert S, Barnes JD, et al. Sedentary behavior research network (SBRN)–Terminology consensus project process and outcome. Int J Behav Nutr Phys Act 2017;14:75.
[14] Guthold R, Cowan MJ, Autenrieth CS, et al. Physical activity and sedentary behavior among schoolchildren: a 34-country comparison. J Pediatr 2010;157.43-49.e1.

[15] Teychenne M, Costigan SA, Parker K. The association between sedentary behaviour and risk of anxiety: a systematic review. BMC Public Health 2015;15:513.
[16] Edwards MK, Loprinzi PD. Experimentally increasing sedentary behavior results in increased anxiety in an active young adult population. J Affect Disord 2016;204:166–73.
[17] Endrighi R, Steptoe A, Hamer M. The effect of experimentally induced sedentariness on mood and psychobiological responses to mental stress. Br J Psychiatry 2016;208:245–51.
[18] Allen MS, Walter EE, Swann C. Sedentary behaviour and risk of anxiety: a systematic review and meta-analysis. J Affect Disord 2019;242:5–13.
[19] Yang Y, Shin JC, Li D, et al. Sedentary behavior and sleep problems: a systematic review and meta-analysis. Int J Behav Med 2017;24:481–92.
[20] Brener ND, Collins JL, Kann L, et al. Reliability of the youth risk behavior survey questionnaire. Am J Epidemiol 1995;141:575–80.
[21] Sharma B, Lee TH, Nam EW. Loneliness, insomnia and suicidal behavior among school-going adolescents in Western Pacific Island countries: role of violence and injury. Int J Environ Res Public Health 2017;14:e791.
[22] Balogun O, Koyanagi A, Stickley A, et al. Alcohol consumption and psychological distress in adolescents: a multi-country study. J Adolesc Health 2014;54:228–34.
[23] McKinnon B, Gariepy G, Sentenac M, et al. Adolescent suicidal behaviours in 32 low- and middle-income countries. Bull World Health Organ 2016;94:340. 50f.
[24] Prochaska JJ, Sallis JF, Long B. A physical activity screening measure for use with adolescents in primary care. Arch Pediatr Adolesc Med 2001;155:554–9.
[25] Higgins JP, Thompson SG. Quantifying heterogeneity in a meta-analysis. Stat Med 2002;21:1539–58.
[26] Felden ÉPG, Leite CR, Rebelatto CF, et al. Sleep in adolescents of different socioeconomic status: a systematic review. Rev Paul Pediatr 2015;33:467–73.
[27] Owen N, Healy GN, Matthews CE, et al. Too much sitting: the population health science of sedentary behavior. Exerc Sport Sci Rev 2010;38:105–13.
[28] Healy GN, Matthews CE, Dunstan DW, et al. Sedentary time and cardiometabolic biomarkers in US adults: NHANES 2003-06. Eur Heart J 2011;32:590–7.
[29] Hansen ALS, Wijndaele K, Owen N, et al. Adverse associations of increases in television viewing time with 5-year changes in glucose homoeostasis markers: the AusDiab study. Diabet Med 2012;29:918–25.
[30] Aoyama S, Shibata S. The role of circadian rhythms in muscular and osseous physiology and their regulation by nutrition and exercise. Front Neurosci 2017;11:63.
[31] Soundy A, Roskell C, Stubbs B, et al. Selection, use and psychometric properties of physical activity measures to assess individuals with severe mental illness: a narrative synthesis. Arch Psychiatr Nurs 2014;28:135–51.
[32] Hallgren M, Owen N, Zeebari Z, et al. Passive and mentally-active sedentary behaviors and incident major depressive disorder: a 13-year cohort study. J Affect Disord 2018;241:579–85.
[33] Horgan A, Sweeney J. Young students' use of the Internet for mental health information and support. J Psychiatr Ment Health Nurs 2010;17:117–23.
[34] Bues M, Pross A, Stefani O, et al. LED-backlit computer screens influence our biological clock and keep us more awake. J Soc Inf Disp 2012;20:266–72.
[35] Caleyachetty R, Echouffo-Tcheugui JB, Tait CA, et al. Prevalence of behavioural risk factors for cardiovascular disease in adolescents in low-income and middle-income countries: an individual participant data meta-analysis. Lancet Diabetes Endocrinol 2015;3:535–44.